United States Patent

[11] 3,580,693

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[21] Appl. No. **808,386**
[22] Filed **Mar. 17, 1969**
[45] Patented **May 25, 1971**

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[32] Priority **Mar. 22, 1968**
[33] **Great Britain**
[31] **13885/68**

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[54] **BOUNDARY LAYER CONTROL DEVICES**
10 Claims, 5 Drawing Figs.

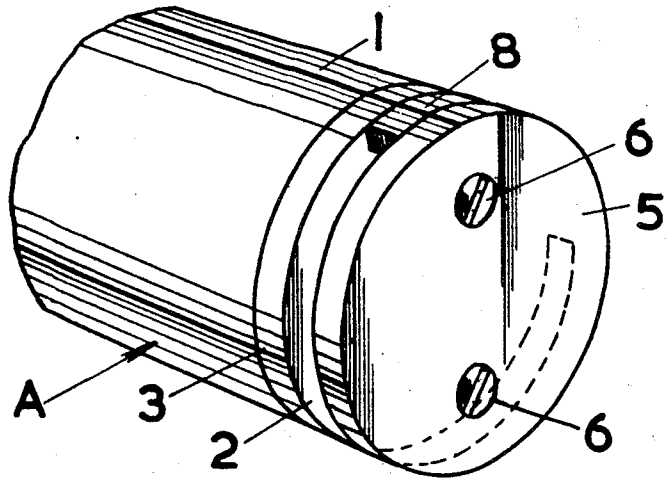
[52] **U.S. Cl.** **416/90,** 416/20
[51] **Int. Cl.** **B64c 27/18**
[50] **Field of Search** 170/135.4, 135.71; 416/4, 20, 31, 42, 90, 98, 117, 118, 119

[56] **References Cited**
UNITED STATES PATENTS

2,333,555	11/1943	Prucha	416/91
2,759,548	8/1956	Yuan et al.	416/91(X)
3,109,494	11/1963	Davidson et al.	416/20
3,109,499	11/1963	Klein	416/91
3,139,936	7/1964	Davidson et al.	416/90(X)
3,348,618	10/1967	Flint et al.	416/90

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ABSTRACT: A rotor blade on which lift is induced by circulation control is provided with a chordwise extending slot at the blade tip formed by a plate spaced from the tip by a distance piece extending around part of the blade periphery towards the rear of the blade, i.e., the slot extends around the front and under part of the blade for about 240°. Air blown from the interior of the blade into the slot is discharged radially as a sheet which forms a pneumatic fence and thus modifies flow over the blade tip. The normal tip vortex can be moved radially outwards relative to the blade root and an appreciable drag reduction obtained. In a variation, air is discharged spanwise relative to the blade.



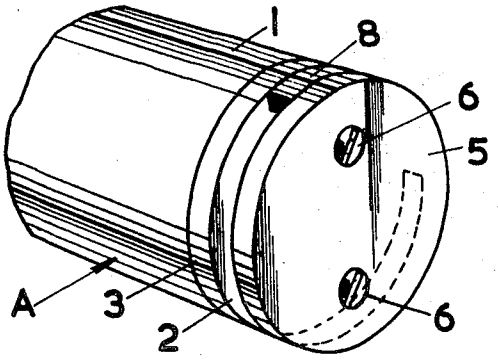


FIG. 1.

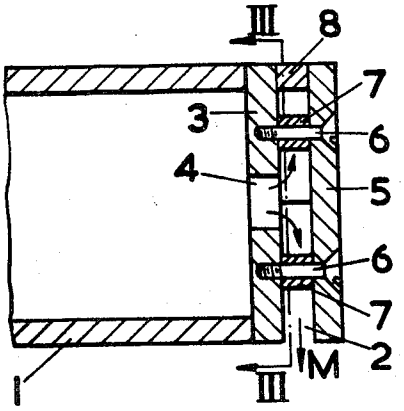


FIG. 2.

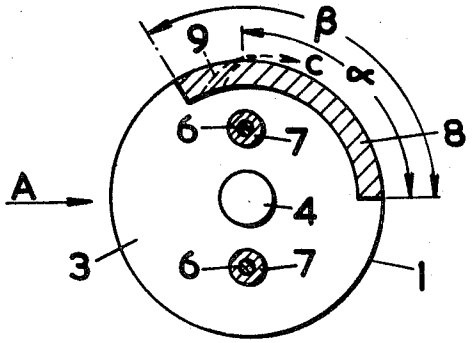


FIG. 3.

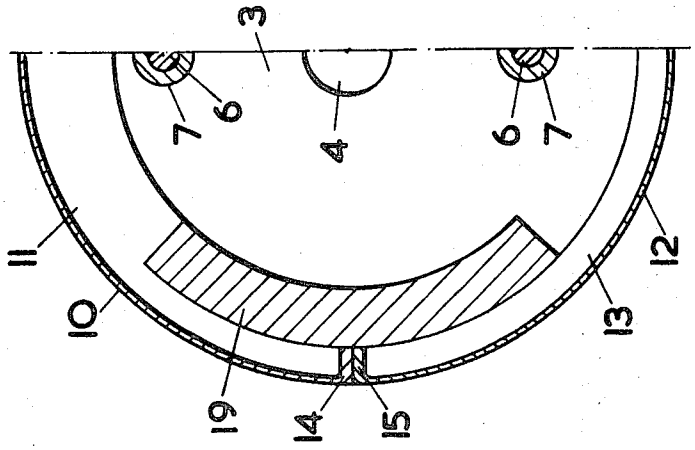


FIG. 5.

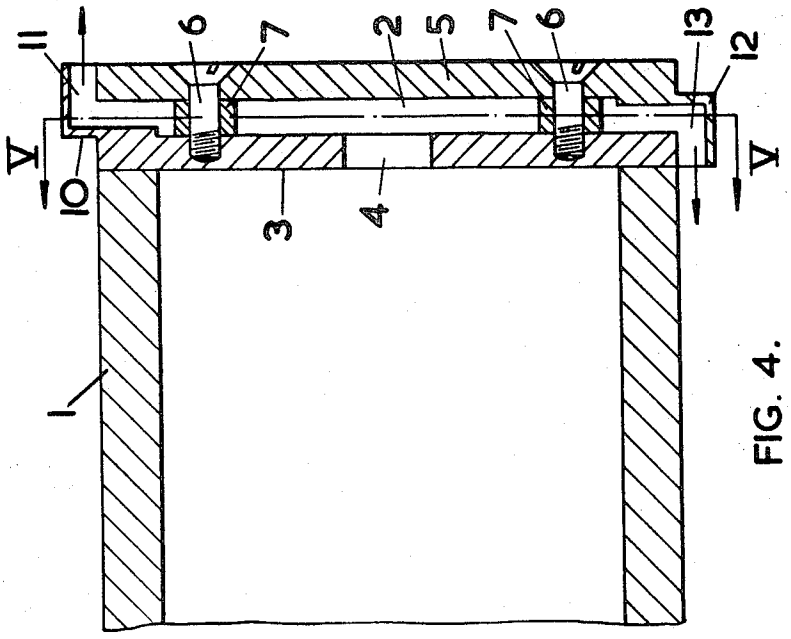


FIG. 4.

BOUNDARY LAYER CONTROL DEVICES

This invention relates to the control of boundary layer flow over aerodynamic-lifting surfaces.

It is known to employ fences in the form of solid baffles on aircraft wings and the like to limit movement of the boundary layer in undesirable directions.

The present invention involves the discharge of sheets of gaseous fluid in the place of the aforesaid baffles, one application being to propellers or helicopter rotors to prevent or restrict radial flow along the blades between regions of differing pressure.

A known phenomenon is the formation of tip vortices due to pressure differences around a blade profile.

Of recent years, there have been various disclosures concerning blades having one or more spanwise extending aperture from which fluid may be discharged as thin streams tangentially over the blade surfaces so as to modify normal circulation around the blades to increase lift coefficients; in the case of blades having a substantially circular cross section, lift may be induced on what would otherwise be a nonlifting section. It has been found that large suction peaks tend to develop near the tips of such blade causing a sharp net increase in mean profile drag coefficient. The reason appears to lie in unfavorable interactions between vortices shed at the blade tips and local flow around the blades in that region. In particular a region of very low pressure can be produced on the trailing edge of a blade near the tip causing a pronounced increase in drag.

According to the invention, means for control of boundary layer flow over an aerodynamic lifting surface comprises at least one slot extending around the periphery of the surface and connected to discharge a sheet of pressurized gaseous fluid externally of the surface.

Slots may be arranged to discharge sheets of fluid substantially radially relative to the spanwise axis of the surface or in a substantially spanwise direction.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying diagrammatic drawings, of which:

FIG. 1 is a general view of the tip section of a circular section blade,

FIG. 2 is an axial section through the tip of the blade of FIG. 1,

FIG. 3 is a transverse section taken on the line III–III in FIG. 2,

FIG. 4 is a similar view of that of FIG. 2 of another blade tip, and

FIG. 5 is an axial half-section taken on the line V-V in FIG. 4.

FIG. 1 shows the tip portion of a circular cross section rotor blade 1, which is mounted for rotation about an axis (not shown) extending vertically relative to the drawing, the nominal incident airflow, indicated by the arrow A, being consequently directed towards the front of the blade according to its direction of rotation. Adjacent to the end of the blade is a slot 2 which extends circumferentially around the blade from a point on the front upper quadrant of the surface thereof forwardly to the blade leading edge then round the under surface of the blade to the trailing edge. The construction of the tip portion is shown in FIG. 2. The blade 1 comprises a hollow cylinder which is partially closed at the tip end by a plate 3 having a central hole 4. A solid pate 5 of the same diameter as the plate 3 is attached to the latter by screws 6 and spaced from it by distance pieces 7 through which the screws 6 pass. A blanking piece 8 of segmental shape is disposed in the annular gap between the plates 3 and 5 and with these defines the slot 2. The blanking piece 8 subtends an angle β of 120° at the blade axis, as may be seen in FIG. 3, and it extends from the blade-trailing edge circumferentially around the upper rear quadrant of the blade and partially into the front upper quadrant. The slot 2 (see FIG. 1) thus subtends an angle of 240° to the blade axis. A typical slot width would be 0.125 in. to 0.25 in. for a blade diameter of 6 in.

A channel 9 (shown in dotted lines in FIG. 3) extends through the boundary thickness of the blade 1 terminating at the blade outer surface as a narrow orifice extending lengthwise along the blade at its uppermost point. Compressed air introduced into the hollow interior of the blade will be discharged from the aperture as a thin stream over the rear surface of the blade, as indicated by the dotted arrow C in FIG. 3, and lift will be generated on the blade as a result, the lift acting generally upwardly according to the Figure. Air will also pass through the hole 4 in the plate 3 to be discharged from the slot 2 as a thin sheet directed generally radially relative to the cross section of the blade (as indicated by the arrow M in FIG. 2). In general, it would probably be desirable for compressed air to be supplied separately to the blade aperture and to the slot 2 since the respective pressure ratios for best results are not necessarily the same.

The thin radially extending sheet acts as a fence which modifies flow around the blade tip. Normally, when a blade as previously described is generating lift due to circulation control the tip lift shedding causes a vortex to form which stabilizes on the rear surface of the blade and forms a pressure gradient in the wake. The effect of the pneumatic fence is to move the position of the tip vortex radially outwards relative to a rotor axis and the magnitude of the minimum static pressure is considerably reduced. The result is an appreciable drag reduction (of the order of 10 percent in one particular case) with consequent reduction in the total power required to drive the rotor even after allowing for the compression of the air involved. The latter is relatively small in volume by comparison with that discharged from the spanwise aperture in the blade.

In some experiments it has been found that the total power consumption (rotor shaft power+ aperture power+ fence power) was at a minimum with a pressure ratio of approximately 1.1.

So far it appears that the best results are obtained with an arrangement substantially as heretofore described, namely a 120° segment located mainly in the upper rear quadrant of a blade with its rear edge displaced by an angle (α in FIG. 3) of 80°—α° from the vertical centerline of the blade. Larger segments appear to give some improvement of the overall lift coefficient of a blade, possibly due to variation of the downward component of the air sheet forming the fence. The best tip drag power function obtained up to the present has been with a 120° segment. Tests also indicate that it is probably important to discharge air to form a fence from some portion of the upper front quadrant of a blade. It is in this region that maximum pressure gradients would exist. In tests where the top front quadrant was blanked off (and the top trailing quadrant was open), tip vortices were greatly intensified. No advantage appears to be obtainable from the use of two segments spaced-apart.

Some of the power expended in the production of a pneumatic fence is probably recovered as a thrust acting to drive a blade in its direction or rotation.

Although a continuous slot has been described, a number of smaller apertures, such as a row of discrete holes, can be used alternatively.

FIGS. 4 and 5 show an arrangement in which sheets of air are discharged from a blade tip in spanwise directions relative to the blade to produce a flow which will oppose a tip vortex. The construction is substantially the same as that described in relation to FIGS. 2 and 3, the same reference numerals being used to described corresponding integers. A circular section blade 1 is partially closed by a plate 3 having a central hole 4 and a solid plate 5 is attached to the plate 3 and spaced from it by screws 6 and distance pieces 7. The circumferential slot 2 thus defined is partially closed by two blanking pieces 19 (one of which is shown in FIG. 5). The blanking pieces 19 are segmental in shape, each subtending an angle of 90° to the blade axis, and being disposed symmetrically about the horizontal (according to the drawing) centerline of the blade at opposite sides of the blade axis. A semicircular shroud 10 having a flange formed along its circumferential periphery is attached

to the plate 3 so that the flange extends over the upper portion, relative to the drawing, of the solid plate 5 with radial clearance to define therewith a semicircumferential slot 11 facing outwardly with respect to the span of blade. Another shroud 12 of similar form is attached to the solid plate 5 so that its flange extends over the lower portion of the plate 3 to define therewith a semicircumferential slot 13 facing inwardly over the blade surface. End pieces 14, 15 formed on the shrouds abut together to prevent flow passing between the respective slots 11 and 13. Compressed air from the interior of the blade 1 will be directed to the slots 11 and 13 to be discharged therefrom as semicircumferential sheets directed outwardly and inwardly relative to the blade span.

Results have shown that the use of a span flow tip fence arrangement gives a greater reduction in tip drag power function than has so far been achieved with radial flow fences. A reduction of over four times the best reduction due to radial flow fences has been obtained. There is a concomitant small reduction in lift although a considerable reduction in tip power function is obtainable before any fall off in lift can be recorded. Tests have indicated that the reason for the reduction in drag is the replacement of tip vortex-indiced suction by a region of pressure corresponding approximately to the total head figure.

Various modifications of the embodiment of FIGS. 4 and 5 can be envisaged. For instance, the shroud 10 might be omitted and the slot 2 blanked off completely in this region so that blowing will occur only radially inwardly along the under part of the blade. Again, the circumferential extent of the slots 11 and 13 might be varied.

All the foregoing has been concerned with the provision of pneumatic fences at the tip of a circular section blade, but a number of such fences might be spaced along the length of a blade.

Pneumatic fences may be applied also to lifting surfaces having other cross sections such as elliptical or a conventional aerofoil profile. One possible application is to blown flaps on a swept wing aircraft.

We claim:

1. A blade for helicopters and the like, having means for controlling fluid flow lengthwise of the blade comprising slotted means formed in the surface of said blade and extending in a chordwise direction around part of said surface and embracing at least a significant portion of the under part of said blade, a source of gaseous fluid, and a connection therefrom for leading fluid to said slotted means for discharge as a sheet therefrom externally of said surface.

2. A blade according to claim 1, wherein said slotted means discharges a sheet of gaseous fluid substantially radially relative to an axis extending lengthwise of said blade.

3. A blade according to claim 1, wherein said slotted means discharges a sheet of gaseous fluid in a substantially spanwise direction relative to the blade.

4. A blade according to claim 3, wherein said slotted means is located adjacent to one end of said blade and discharges a sheet of gaseous fluid inwardly relative to said end.

5. A blade according to claim 3, comprising further slotted means extending around a further part of said blade in substantially the same transverse plane as said slotted means to discharge a sheet of gaseous fluid in a substantially opposite direction to that discharged by said slotted means.

6. A blade according to claim 1 having a substantially circular cross section.

7. A hollow blade for helicopter and like rotors of substantially circular cross section having aperture means extending along its length connected to discharge a stream of gaseous fluid tangentially over the surface of the blade to induce lift thereon, comprising a plate spaced from the tip of the blade to define therewith a slot extending peripherally relative to the blade surface, blanking means closing off a portion of said slot, a connection between said slot and the interior of the blade, and a connection between the interior of the blade and a source of pressurized gaseous fluid whereby the plate is arranged so that fluid introduced into the blade will be discharged from the slot, substantially radially relative to the lengthwise axis of the blade.

8. A blade according to claim 7 in which the blanking means closes off a portion of the slot which extends substantially around the rear upper quadrant of the blade relative to normal airflow around the blade.

9. A blade according to claim 7 in which the closed off portion of the slot subtends an angle at the blade axis of the order of 120°.

10. A blade according to claim 8 in which the blanking means has a trailing edge which is positioned within an angle in the range 80° to 90° subtended at the blade axis from the vertical centerline of the blade.